Kennedy Space Center – Constellation Project Office

CONSTELLATION

Integration Testing of Space Flight Systems

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Presentation Outline

- History of Multi-Element Integration Tests (MEITs)
  - MEIT Concept
  - Previous MEITs
  - Major Problems Found
  - Benefits
- Integrated Testing at KSC for the Constellation Program
  - Integrated Tests
    - Multi-Element Integrated Tests (MEITs)
    - Flight Element Integrated Tests (FEITs)
    - Integrated Verification Tests (IVTs)
- Summary

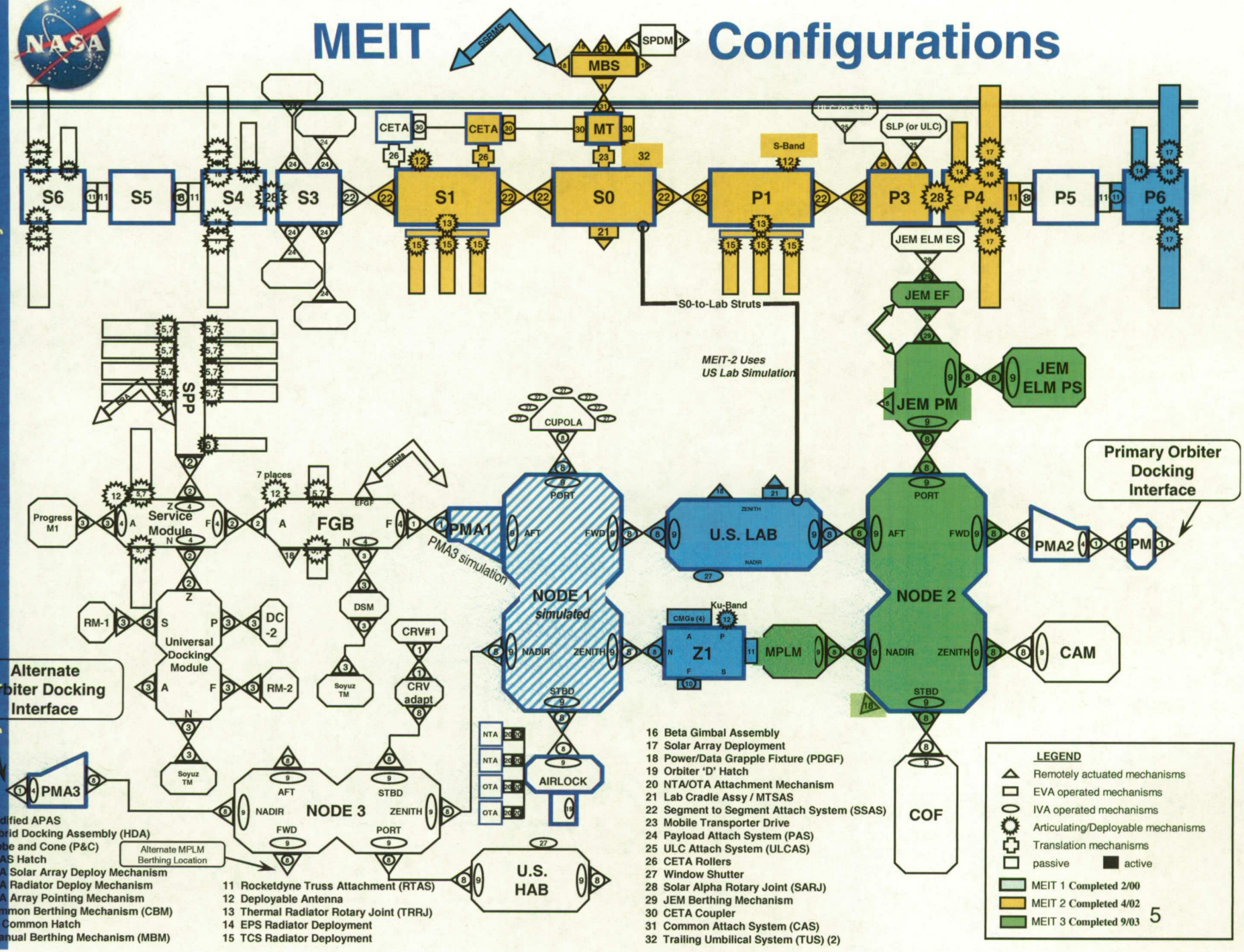
History

- "Ship and shoot" was the strategy for the International Space Station Program (ISSP) during the early 1990's
  - It proposed transporting flight elements directly from the factory to the launch site and begin the mission without further testing.
  - Factory level testing and element interface verifications at the subsystem-level, and interface analysis were all that was planned.
- Before the end of that decade a shift in testing strategy occurred within the ISSP
  - The ISSP adopted a more integrated approach for ground validation of it's flight hardware.
  - Availability of elements at the launch site created a feasible opportunity to test multiple elements together.
  - The notion of validation testing on the ground was presented and accepted by the ISSP due to the criticality of the on-orbit functionality, including safety concerns for the crew .

History (cont)

- Multi Element Integration Tests (MEITs) and Integrated Systems Tests (ISTs)
  - Risk mitigation tests performed on the ground, used for validating the operation of the flight elements and their systems in an environment that is as flight-like as possible.
  - These tests were used to demonstrate the interoperability and functionality of Space Station elements as integrated "in-space" assemblies on the ground before they were assembled in space for the first time.
    - Space Station element-to-element interface capability was verified as well as systems end-to-end operability with hardware and software.
    - Mission Sequence Testing (MST), also known as "end-to-end" integration testing, included a full-up configuration with the Mission Control Center, Tracking Data Relay Satellite System (TDRSS), and the "station" operating on the ground.
    - Also verified limited on-orbit system compatibility.

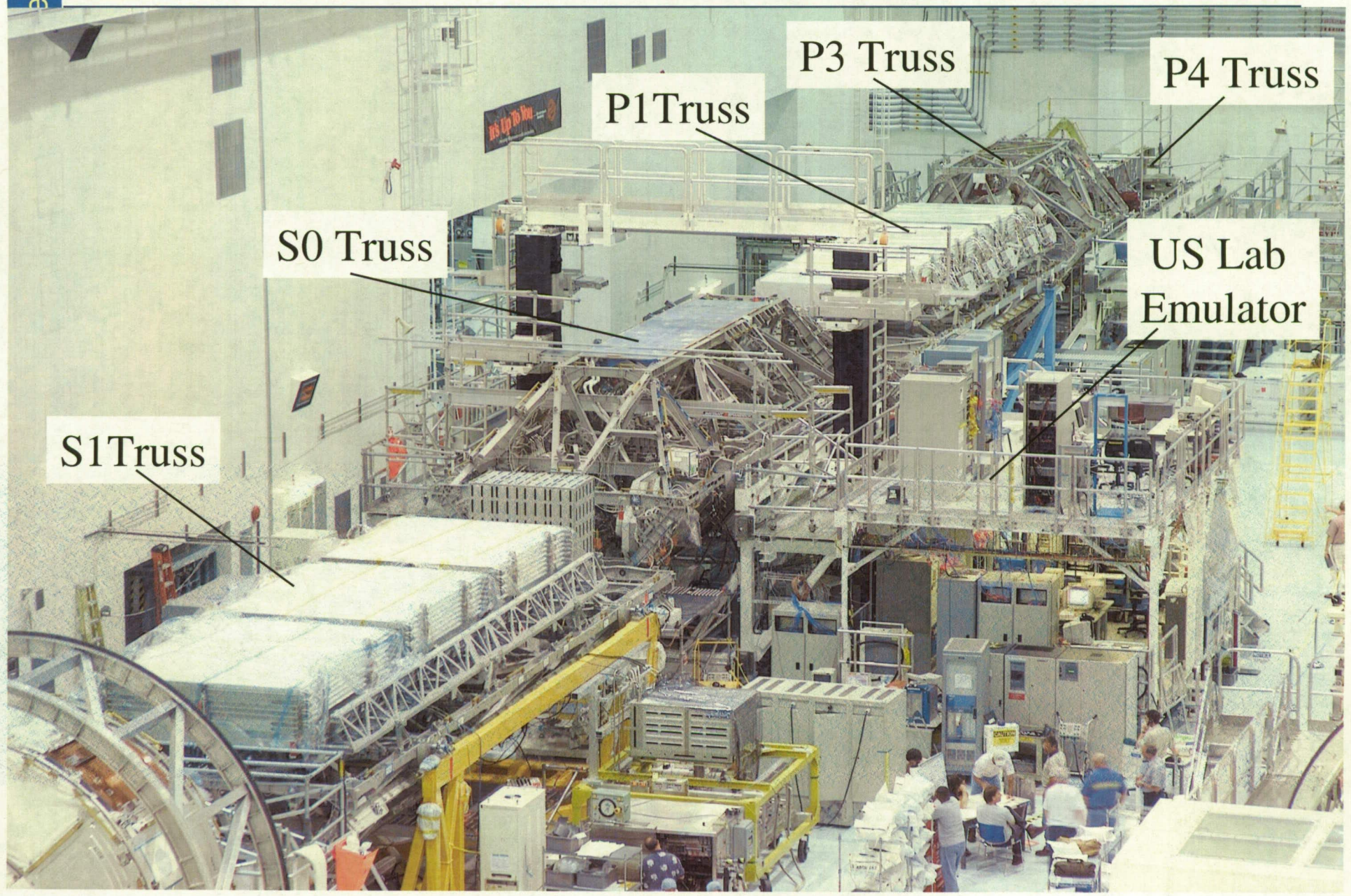
MEIT Configurations



1 Modified APAS
2 Hybrid Docking Assembly (HDA)
3 Probe and Cone (P&C)
4 APAS Hatch
5 RSA Solar Array Deploy Mechanism
6 RSA Radiator Deploy Mechanism
7 RSA Array Pointing Mechanism
8 Common Berthing Mechanism (CBM)
9 US Common Hatch
10 Manual Berthing Mechanism (MBM)
11 Rocketdyne Truss Attachment (RTAS)
12 Deployable Antenna
13 Thermal Radiator Rotary Joint (TRRJ)
14 EPS Radiator Deployment
15 TCS Radiator Deployment
16 Beta Gimbal Assembly
17 Solar Array Deployment
18 Power/Data Grapple Fixture (PDGF)
19 Orbiter 'D' Hatch
20 NTA/OTA Attachment Mechanism
21 Lab Cradle Assy / MTSAS
22 Segment to Segment Attach System (SSAS)
23 Mobile Transporter Drive
24 Payload Attach System (PAS)
25 ULC Attach System (ULCAS)
26 CETA Rollers
27 Window Shutter
28 Solar Alpha Rotary Joint (SARJ)
29 JEM Berthing Mechanism
30 CETA Coupler
31 Common Attach System (CAS)
32 Trailing Umbilical System (TUS) (2)

LEGEND
- Remotely actuated mechanisms
- EVA operated mechanisms
- IVA operated mechanisms
- Articulating/Deployable mechanisms
- Translation mechanisms
- passive / active
- MEIT 1 Completed 2/00
- MEIT 2 Completed 4/02
- MEIT 3 Completed 9/03

MEIT 2 Hardware at KSC



Problems Found in MEITs (top examples)

- P6 truss failed to power up due to Auxiliary Power Converter Unit (APCU) under voltage trip condition.
  - Impact: Unable to start P6 on Orbit.
- US Lab critical activation took 36 hours during the first MEIT Power-up (computer/procedure problems), Requirement <2 hrs. During MEIT regression Mission Sequence Test, Critical Activation took 1 hr, 15 minutes.
  - Impact: Loss of Lab element during on-orbit activation due to thermal loading.
- Command and Control (C&C) computers failed several times due to task overrun problems (CPU utilization problems).
  - Impact: Significant operational issues (Loss of Vehicle commanding, Vehicle health visibility, visibility to crew/ground) would occur because of continued loss of C&C computers.

Problems Found in MEITs (top examples) (continued)

- Video lines were swapped between Trailing Umbilical Systems 1,2 (NASA) and Mobile Base System (Canadian Space Agency)
  - Impact: Significant operational impact to manually route video signals. Extra Vehicular Activity (EVA) would have been required to replace two harnesses to correct the problem.
- C&C computers failed when performing synchronization to Global Positioning System (GPS) time
  - Impact: Loss of accurate GPS capability, degraded attitude control capability until development /testing and on-orbit upload of new software patch.
- Quality of Space to Ground Audio was unacceptable
  - Impact: Operation and potential safety impact to crew due to lack of understanding between Crew/Ground.

MEIT Benefits

- **Significant findings from MEIT have created an opportunity to correct major operational problems which would have resulted in:**
  - Cost/Schedule Slip
    - Major milestone slippage in the Program
  - Critical On-orbit Operations impacts
    - Safety concerns for the crew
    - Loss of mission objectives
    - Loss of flight hardware
  - Nominal Operations impacts
    - Unknown operation risks (loss of redundancy capability)
  - Unplanned EVA's

The cumulative effect of identifying & resolving integrated hardware, software and procedure problems before flight has proven to save the International Space Station Program major on-orbit issues.

Integrated Testing at KSC for the Constellation Program (CxP)

- Testing that occurs between two or more individual Constellation Systems to verify the interfaces between those Systems and to validate the integrated Systems' functionality and interoperability.
- Includes testing mechanical, electrical, data and fluid interfaces.
- Integrated testing applies to the in-space flight and integrated vehicle stack configurations.
  - Multi-Element Integration Testing (MEIT)
  - Flight Element Integration Testing (FEIT)
  - Interface Verification Testing (IVT)

Constellation Architecture

Crew Exploration Vehicle – CEV/Orion
Lunar Lander – Lander/Altair
Crew Launch Vehicle – CLV/Ares I
Cargo Launch Vehicle – CaLV/Ares V

Constellation Architecture

Crew Vehicles & Systems

- **CEV**
- **Lunar Lander**
- **EVA Systems**
- **Flight Crew Equip.**
- **Lunar Surface Systems**

Launch Vehicles & Systems

- **CLV**
- **CaLV**

Ground & Mission Systems

- **Ground Systems**
- **Mission Systems**

Future

CLV Elements
- -1st Stage
- -Upper Stage
- -Upper Stage Engine

CEV Elements
- -Launch Abort System (LAS)
- -Crew Module (CM)
- -Service Module (SM)
- -Spacecraft Adapter (SA)

Subsystems: examples include data, power, thermal, etc.

CxProgram	Architecture	Level 2
Project ↓	System	Level 3
	Element	Level 4
	Subsystem	Level 5
	Future	

Multi-Element Integration Test (MEIT)

MEIT:

- An integration test between two or more flight systems that will be launched on separate launch vehicles and integrated together for the first time in space.
  - Interfaces between the flight systems, mission systems, and other appropriate CxP/ISSP and external systems may be also tested as part of each MEIT.

- The primary objectives of MEIT are:
  - Demonstrate the interoperability, functionality, and stability of the flight systems, elements, and sub-systems as an integrated "in-space" vehicle assembly on the ground before they are assembled in space for the first time.
  - Validate critical mission sequence activities and flight procedures prior to their first-time execution in-flight.

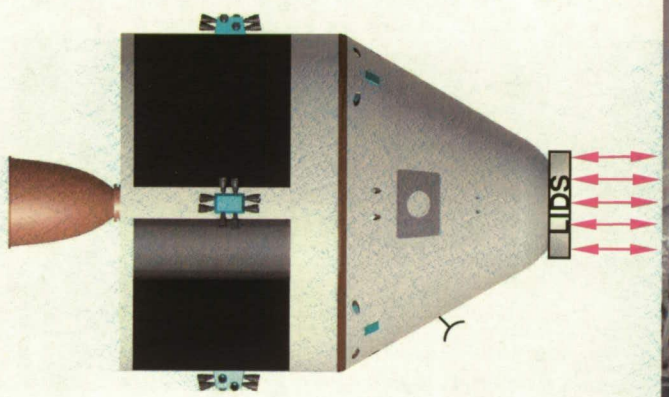
MEIT (continued)

- MEIT serves a training ground:
  - Flight crew and trainers
  - Mission Operations Division (MOD)/Mission Control Center (MCC) personnel
  - Constellation system engineers
- MEITs are executed after all of the system-level requirements have been satisfied by the involved Project offices and those offices declare their system designs as verified for flight.
- MEITs are one time tests with a potential for a follow-on regression test
  - Performed prior to first crewed missions.
- Use of flight-like emulators and cables/connectors may be used when integration between the flight systems is not practical.
- Planned MEITs:
  - CEV to International Space Station (ISS) (using ISS emulation)
  - CEV to Lunar Lander/Earth Departure Stage (EDS) (using EDS emulation)

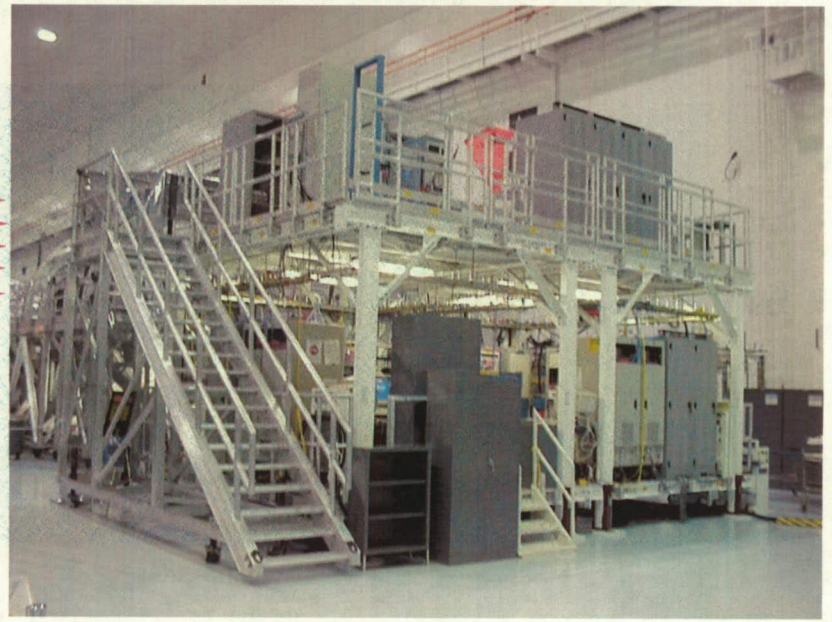
MEIT 1: CEV to ISS (emulator)

- CEV-International Space Station (ISS) MEIT
  - To be performed in the year 2012, prior to first ISS flight.
  - Tests interoperability/functionality and all functional interfaces: data, audio, video, RF, power.
  - End-to-end test with Mission Control performed via TDRSS.
  - Uses emulation in place of ISS flight hardware.
  - Mated with flight-like cables and connectors.

CEV

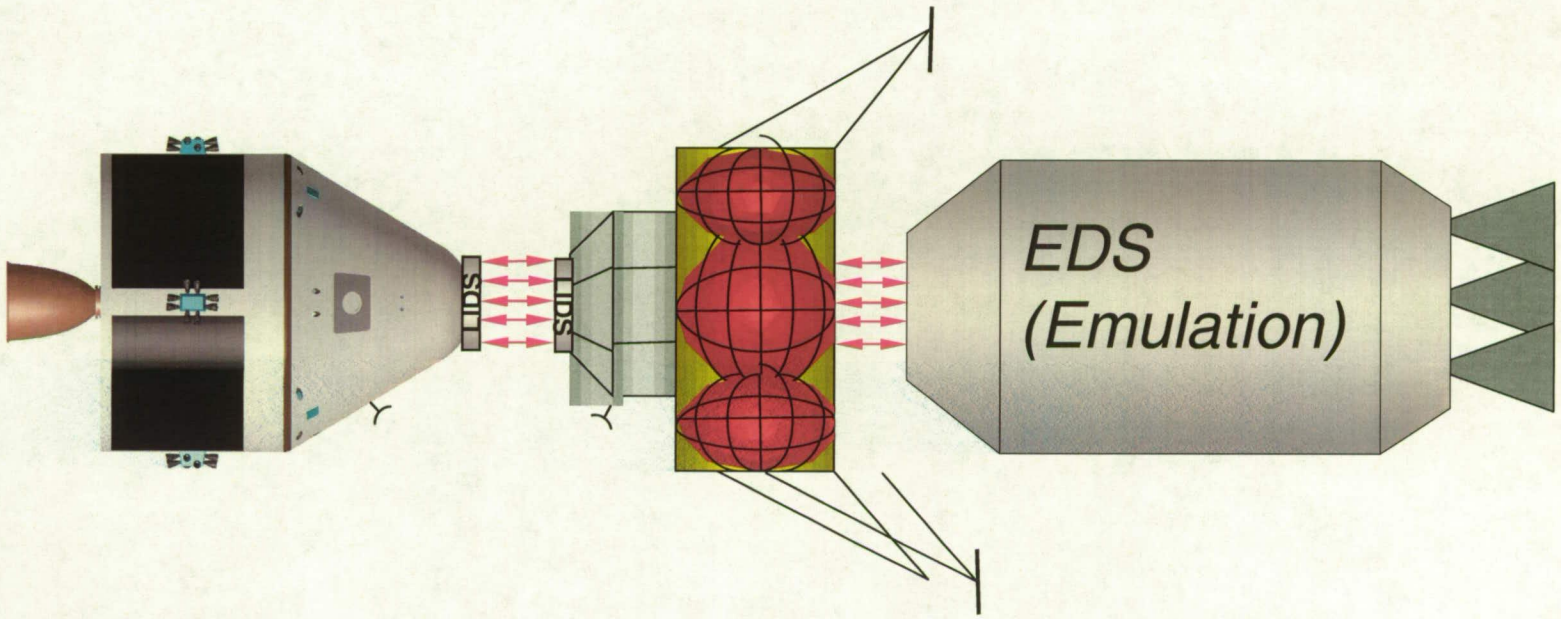


ISS Flight Emulator



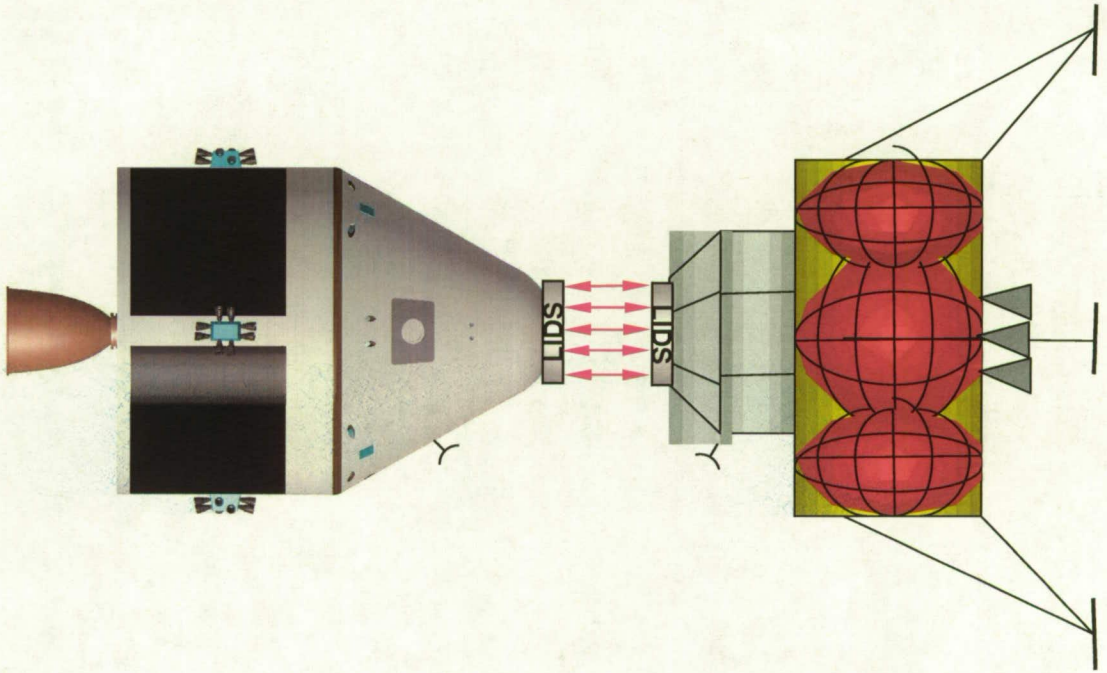
MEIT 2: Test Configuration #1 (TC1)

CEV to Lunar Lander with EDS Emulation



MEIT 2: Test Configuration #2 (TC2)

CEV to Lunar Lander



Flight Element Integration Test (FEIT)

FEIT:

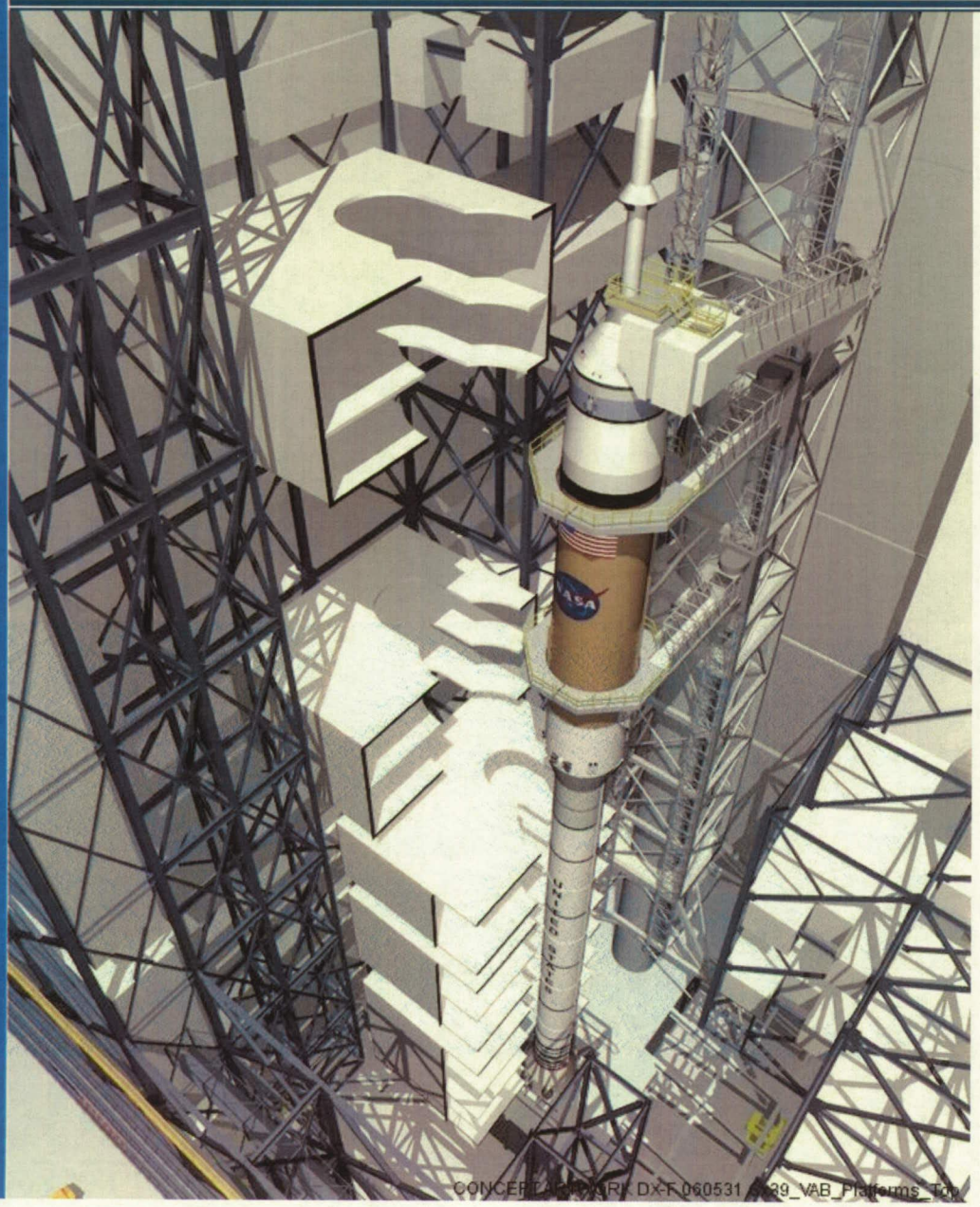
- An integration test between the new or significantly modified systems and elements being assembled into an integrated launch vehicle for the first time.
  - Interfaces between the flight systems, ground systems, mission systems, and other appropriate CxP and external systems may be also tested as part of each FEIT.

- The primary objectives of the FEIT are:
  - Demonstrate the interoperability, functionality, and stability of the flight systems, elements, and sub-systems as an integrated "launch vehicle" assembly prior to the first operational test flight of that particular launch vehicle configuration.
  - Validate critical mission sequence activities and flight procedures prior to their first-time execution.

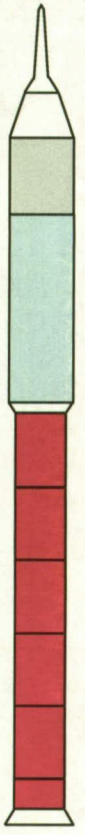
FEIT (continued)

- FEITs are executed after all of the system-level requirements have been satisfied by the involved Project offices and those offices declare their system designs as verified for flight.
- FEITs are planned and scheduled as part of the assembly and preparation of the integrated launch vehicle.
- FEITs are currently planned for every test flight (except for Ares 1-X).
- Planned FEITs:
  - CEV/CLV
  - Lunar Lander/EDS/CaLV

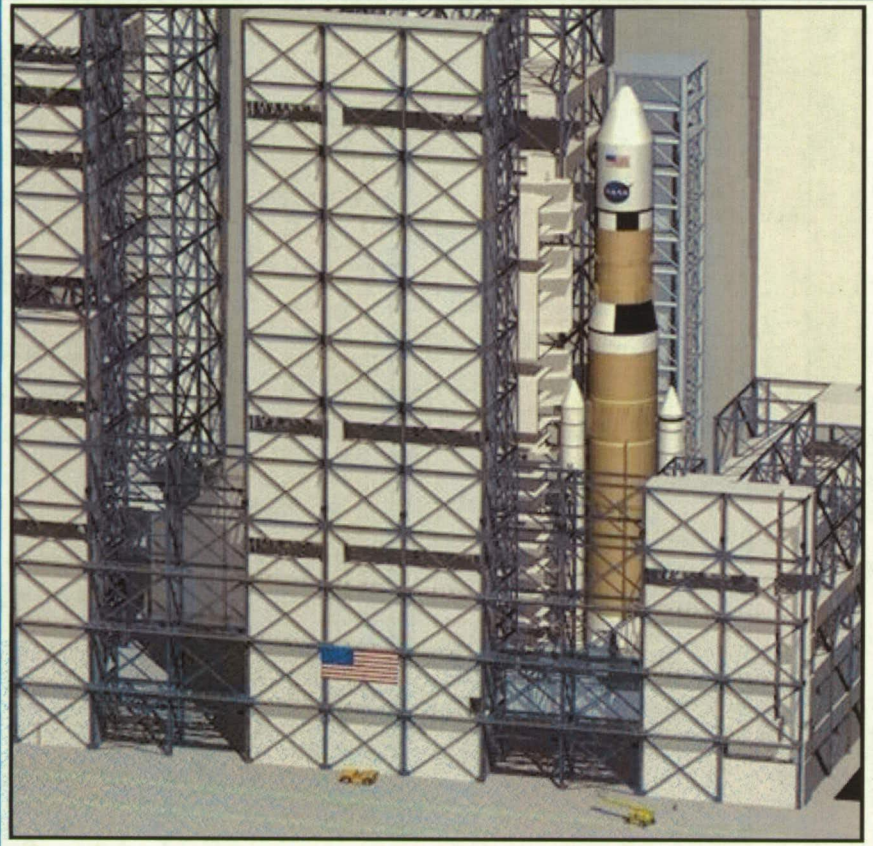
FEIT 1 – Ares 1 Launch Vehicle Stack

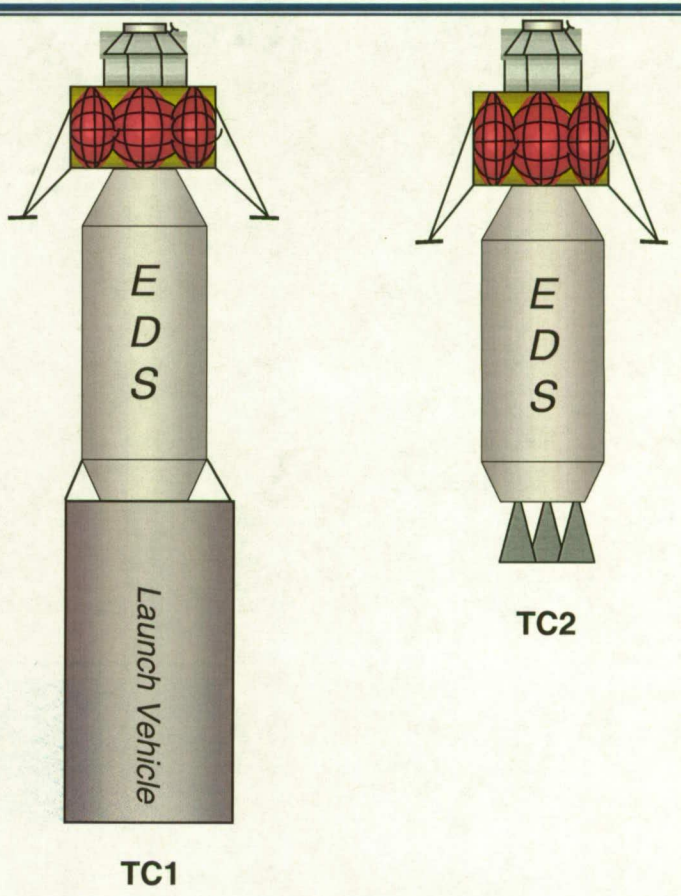


- **Test Configuration:**
  - CEV/CLV Integrated Stack
  - Ground Systems
  - Missions Systems
  - SCaN (Space Communications and Navigation)



FEIT 2 – Ares V Launch Vehicle Stack





- **Test Configurations:**
  - Lunar Lander/EDS/CaLV (TC1)
    - Integrated Stack
  - Lunar Lander/EDS (TC2)
    - On-orbit Configuration

- **Both test configurations include:**
  - Ground Systems
  - Missions Systems
  - SCaN (Space Communications and Navigation)

Interface Verification Testing (IVT)

- Interface Verification Testing (IVT) verifies the mechanical and/or electrical interfaces between two or more flight systems after these systems have been mated.
- IVT consists of the minimal set of activities to verify the integrity of all physical and functional interfaces between the systems involved for each specific vehicle stack configuration.
- IVTs are performed as a subset of the FEITs during the flight tests and then performed for every flight after Full Operational Capability (FOC) has been obtained with the flight and ground Systems.
- MEITs/FEITs would be required if any significant design upgrades or modifications have occurred.

Summary

- Based on the previous success' of MEITs for the International Space Station Program, these type of integrated tests have also been planned for the Constellation Program:
  - MEIT
    - CEV to ISS (emulated)
    - CEV to Lunar Lander/EDS (emulated)
    - Future: Lunar Surface Systems and Mars Missions
  - FEIT
    - CEV/CLV
    - Lunar Lander/EDS/CaLV
  - IVT
    - Performed as a subset of the FEITs during the flight tests and then performed for every flight after Full Operational Capability (FOC) has been obtained with the flight and ground Systems.

"Standing alone, components may function adequately, and failure modes may be anticipated. Yet when components are integrated into a total system and work in concert, unanticipated interactions can occur that can lead to catastrophic outcomes". (Columbia Accident Investigation Report (CAIB) Report 2003)